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# Oscillations of the positive column plasma caused by propagation of ionization wave and the two-dimensional structure of striations

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*Time resolved measurements of the electron energy distribution function (EEDF) and plasma potential in longitudinal and radial directions under the presence of S- and P- striations in neon were performed. The potential was measured with high spatial resolution by means of simultaneous displacement of electrodes relative to stationary probe in different radial positions. A method of decomposition of the spatio-temporal structure of the potential is proposed. The potential is shown to be composed of the plasma oscillations and the ionization wave potential. Experiments revealed two-dimensional structure of the striation potential field. Qualitative considerations of the origins of this structure are discussed.*

## 1. Introduction

Plasma of the positive column of glow discharge is stratified under wide range of discharge conditions. Propagation of the ionization waves (striations) is accompanied by oscillations of the plasma potential. These oscillations should be taken into account when measuring spatial potential profile [1]. Correct measurement of potential allows one to analyse electrons kinetics in striations. In this paper the space and time resolved measurements of the potential within striation are presented. Two-dimensional structure of the potential in the stratified positive column is investigated. Decomposition method of the spatio-temporal potential distribution in terms of potential oscillations and wave propagation is proposed.

## 2. Experimental setup and measurement technique

Measurements were carried out in discharge tube with inner diameter of 40 mm and distance between electrodes of 55 cm. Electrodes were moveable in axial direction allowing direct space resolved measurements in positive column. The probe was moveable in radial direction. Spatial resolution in axial direction was limited by the length of the probe which was equal to 1.5 mm. Measurements were carried out in neon discharge at pressures  $p = 1.5$  Torr for S-striation and  $p = 1.0$  Torr for P-striation. Discharge current in both cases was equal to 10 mA. Potential drops over striation lengths were equal to 19 V for S-striation at length  $L_S$  equal to 10.15 cm and 9.5 V over  $L_P = 5.1$  cm for P-striation. Values of mean electric field were equal  $E_0 = 1.9\text{V/cm}$  in both cases.

## 3. Decomposition of the measured potential onto wave and oscillations

Let us suppose that measured space-time potential structure has a form of

$$\Phi_{\text{exp}}(x, t) = -E_0 x + \Phi_{\text{wav}}(x - vt) + \Phi_{\text{osc}}(t).$$

Eliminating the potential created by the constant electric field  $E_0 x$  and introducing substitution ( $\xi = x - vt, t$ ) one becomes a matrix in the form

$$\tilde{\Phi}_{\text{exp}}(\xi, t) = \Phi_{\text{wav}}(\xi) + \Phi_{\text{osc}}(t) \quad (1)$$

where  $\tilde{\Phi}_{\text{exp}}(\xi, t) = \Phi_{\text{exp}}(x, t) + E_0 x$ . It is seen from (1) that when the  $\xi$  value is constant, the term on the left hand side of (1) gives  $\Phi_{\text{osc}}(t)$  and when the  $t$  is constant it gives  $\Phi_{\text{wav}}(\xi) = \Phi_{\text{wav}}(x - vt)$ .

This allows one to expand the measured space-time potential structure onto the potential of ionization wave, that depends on  $x - vt$  and potential oscillations depending only on time. Results of such decomposition are shown in figure 1.

## 4. Two-dimensional structure of ionization waves

Two-dimensional structure of the potential in the striations is shown in figure 2. It is clearly seen, that the potential which was measured with the help of the moveable electrodes and probe has a form of superposition of the steady-state positive column potential  $\varphi^{(0)}(x, r) = -E_0 x + \varphi_0(r)$  and the two-dimensional potential of ionization wave  $\tilde{\varphi}(x, r)$ . Radial potential profile is periodically changed in the direction of wave propagation.

Two-dimensional potential perturbations could be analysed on the basis of ion motion equation, which can be written in the following form

$$\frac{\partial n(\varphi)}{\partial t} + b_1 \text{div}(n(\varphi) \text{grad}(\varphi)) = I(\varphi) \quad (2)$$

where the electron density  $n(\varphi)$  and ionization rate  $I(\varphi)$  are the functions of the radial potential. Both of them can be considered as the sum of the values for the axially homogeneous positive column and small

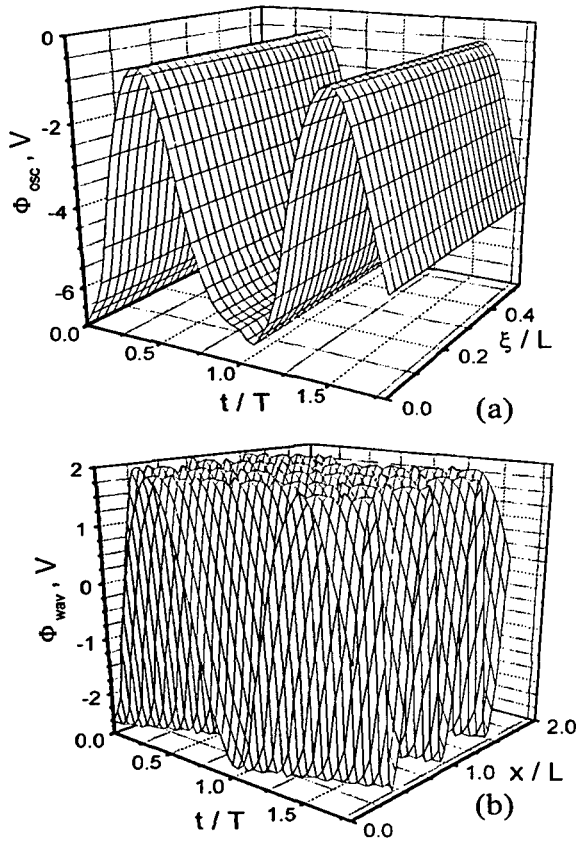


Figure 1: Decomposition of the measured spatio-temporal potential onto potential on oscillations and wave. a - oscillations of the plasma potential as a whole, b - potential of the ionization wave.

wave-like additions. Let us suppose that potential perturbations have the form of the wave which propagates in longitudinal direction  $x$  with an amplitude depending on  $r$ .

$$\tilde{\varphi}(x, r) = \Phi(r) \exp(ikx) \exp(\delta t)$$

Scale  $k = 2\pi/L$  of the axial inhomogeneity is defined by electron kinetics and remains constant. Longitudinal gradients could be neglected as far as the wavelength is much longer than the tube radius  $L \gg R$ . Linearized equation for the wave amplitude  $\Phi(r)$  has the following form

$$\frac{1}{r} \frac{\partial}{\partial r} r \frac{\partial \Phi}{\partial r} + \left( \frac{1}{b_1 n} \frac{\partial n}{\partial \varphi} \delta - \frac{1}{b_1 n} \frac{\partial I}{\partial \varphi} + \frac{1}{nr} \frac{\partial}{\partial r} r \frac{\partial n}{\partial r} \right) \Phi = 0 \quad (3)$$

Equation (3) with the boundary condition

$$\left. \frac{\partial \Phi}{\partial r} \right|_{r=R} = 0$$

is an eigenvalue problem where the eigenvalues determine a sign of disturbance decrement  $\delta$  and eigen-

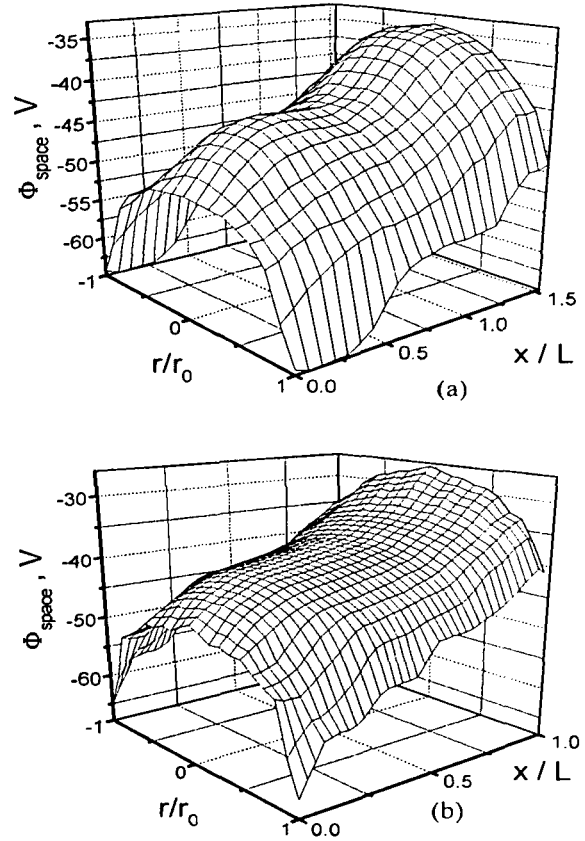


Figure 2: Measured two-dimensional structures of the potential in S-(a) and P-(b) striations.

functions define a form of this disturbance. Similar eigenvalue problem for the electron density perturbation was considered in paper [2]. It can be shown [2] that the largest decrement  $\delta$  corresponds to the first alternating-sign eigenfunction resulting in the radial potential perturbation in the following form

$$\Phi(r) = J_0 \left( t_1 \frac{r}{R} \right)$$

Where  $t_1$  is the first root of Bessel function of first order  $J_1(t_1) = 0$ .

## 5. Acknowledgements

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